Improving Market Clearing Software Performance to Meet Existing and Future Challenges – MISO's Perspective

FERC Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software

June 27-29, 2016

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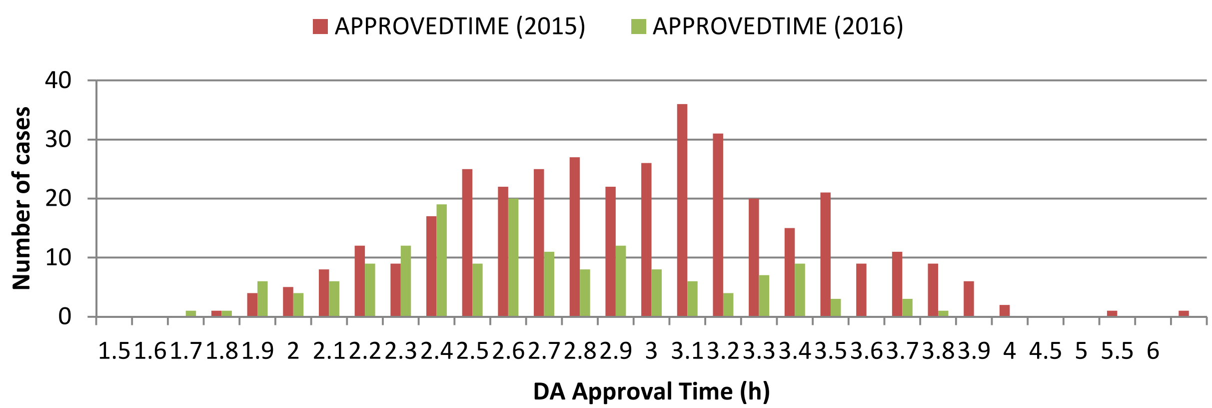
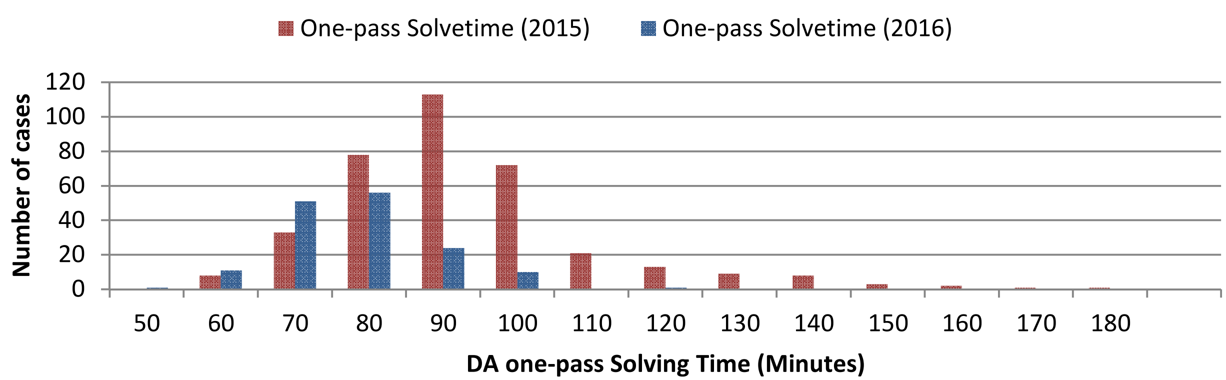
Dedicated efforts in improving day-ahead (DA) software and clearing process performance

- New market clearing software delivered and activated in 2016 has resulted in significant improvement
- More upcoming deliveries to meet 3-hour clearing goal





DA Market Clearing Process

- Preparation and adjustment of case inputs from operators
  - Adjustment for DC and AC flow differences
  - VLR commitment
- Adjustment from IMM
- “What-if” analysis

Security Constrained Unit Commitment (SCUC)
Security Constrained Economic Dispatch (SCED)

Network Security Analysis
- State Estimation
- Contingency Analysis (RTCA/SFT)
- Topology Processing

Area 2

- Incremental solve capability [a]
- Commit reason [a]
- Polish for non-zero MIP gap [a]
- Incorporate VLR constraints and commit reason identification [b]

Area 3

- Incremental processing [a]
- New heuristic approaches [a]
- Improve MIP formulation [b]
- Constraint and variable hints to solver [c]
- Parallel computing [c] and HPC [d]

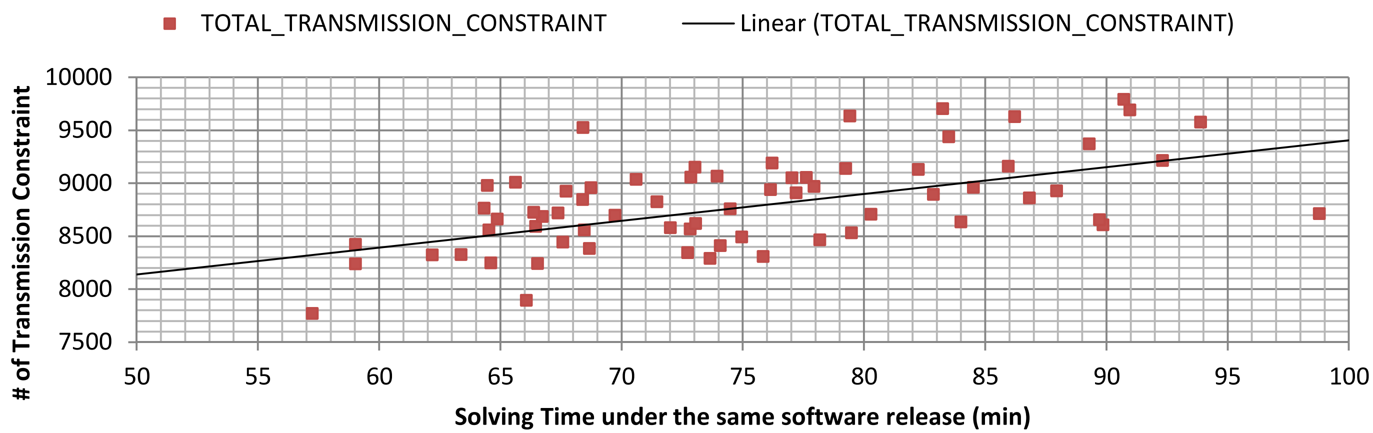
Area 1

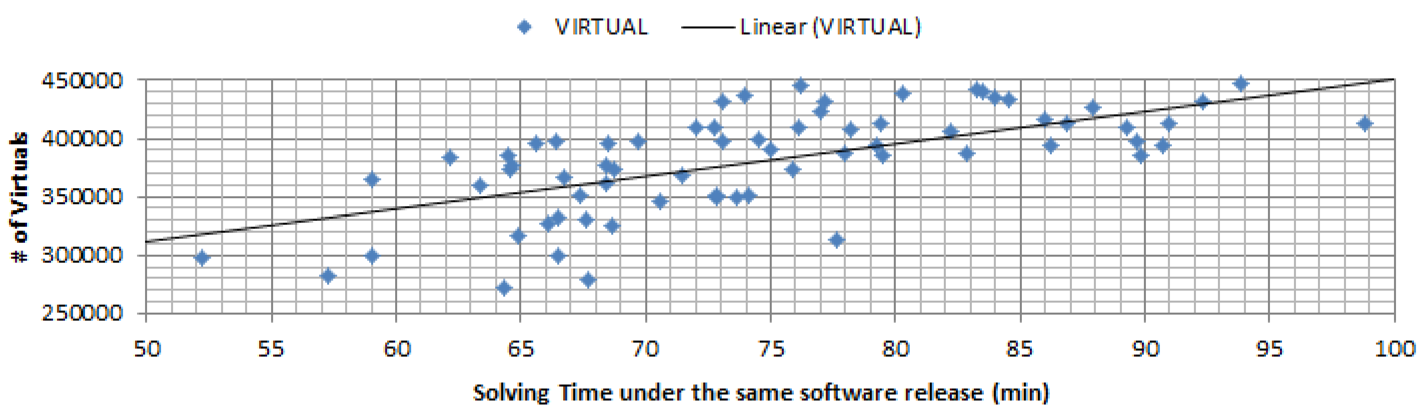
- Improve efficiency on data exchange [a]
- Avoid putting large network model in CPLEX (not very efficient in processing sparse matrix) [a]
- Improve parallelization [b]

a. Delivered; b. Upcoming delivery; c. POC with vendors; d. ARPA-E project

Driving factors for solving time

- Number of transmission constraints and number of virtuals are the two main driving factors under current solution process
- More complicated SCUC modeling (e.g. configuration based combined cycle) can significantly increase the solution time





Implemented enhancement

- Joint work with GE

Improved robustness and efficiency of SCUC[1]

- Feasibility check to resolve conflict data in preprocessing to avoid large violation penalties
- New heuristic solving methods
- Incremental solving capability
  - Incremental input processing
  - Incremental solving SCUC starting with existing commitment solutions
- Commit reason identification and polishing for non-zero MIP gap

Improved efficiency on network analysis and the iteration process

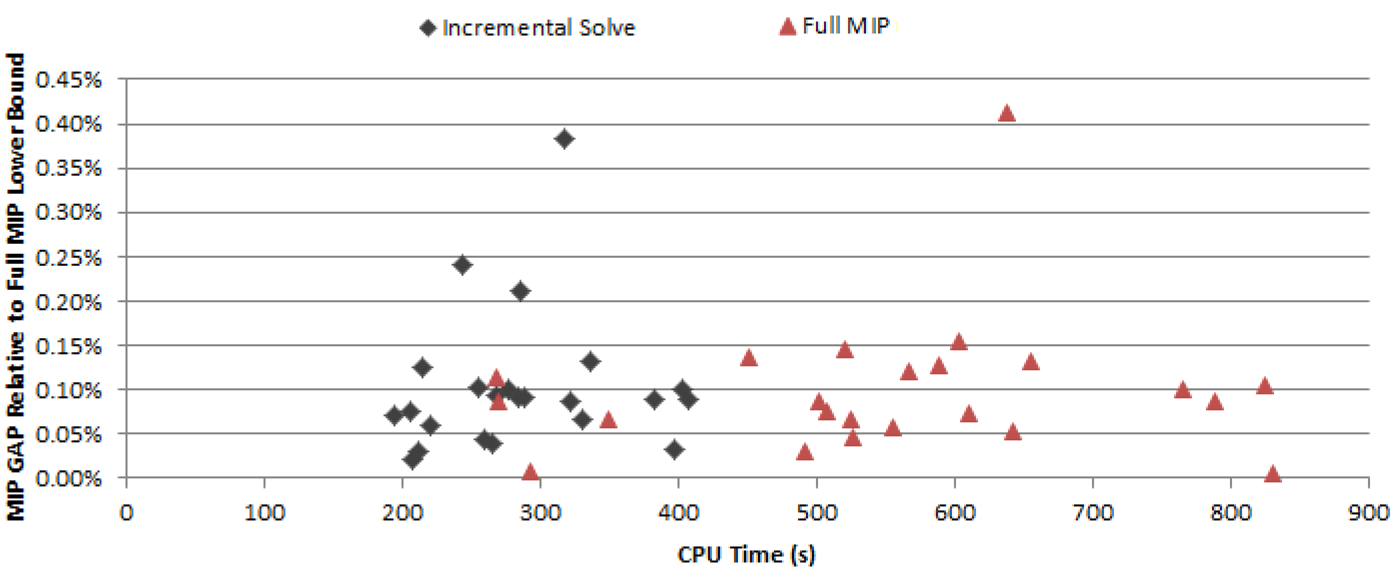
- Improved parallelization on SFT and sensitivity calculations
- Avoid putting large network model in CPLEX (not very efficient in processing sparse matrix)
- Improved iteration process between SCUC/SCED and SFT

[1] Yonghong Chen; Aaron Casto; Fengyu Wang; Qianfan Wang; Xing Wang; Jie Wan, "Improving Large Scale Day-Ahead Security Constrained Unit Commitment Performance", IEEE Trans. Power Syst., Accepted

Incremental solving approach starts with existing commitment solution

- Focuses on commitment variables of "out-of-money" units
- Focuses on binding or near binding transmission constraints
- Usually can solve much faster and with good solution quality
  - However, lack of global lower bound to justify optimality

- Next step: working with Gurobi on constraint hint and variable hint as well as distributed and parallel computing
  - Gurobi has introduced lazy constraint and variable hints in its MIP solver



Results (23 normal DA cases)

Software enhancement to be delivered in 2016-early 2017

Incorporating Voltage and Local Reliability (VLR) constraints[2] and VLR commitment reason identification

- Incorporating binary constraints to meet VLR commitment requirement
- Developing approach to identify resources committed for VLR constraints for proper uplift cost allocation

SCUC formulation improvement[3]

- Tighter piece-wise linear energy offer curve modeling
- Group variables with same impact on transmission constraints to significantly reduce non-zeros

Further Improving parallelization for iteration with SFT

Apply incremental processing and solving capability for IMM process

[2] Yonghong Chen, David Savageau, Fengyu Wang, Aaron Casto, "Voltage and Local Reliability Commitment under Electricity Market Operations," IEEE PES General Meeting, Jul. 2016.

[3] Yonghong Chen, "MIP Formulation Improvement for Large Scale Security Constrained Unit Commitment", http://www.optimization-online.org/DB_HTML/2016/05/5430.html

SCUC formulation improvement[3]

- Tighter piece-wise linear energy offer curve modeling (PWL)
  - Typical PWL formulation for convex incremental energy offer*:

$$p_{j,t} = \gamma_{j_0} \cdot P_{j_0,t} + \gamma_{j_1} \cdot P_{j_1,t} + \cdots + \gamma_{j_m} \cdot P_{j_m,t}$$

$$C_{j,t}^{P}(p_{j,t}) = \gamma_{j_0} \cdot C_{j,t}^{P}(P_{j_0,t}) + \cdots + \gamma_m \cdot C_{j,t}^{P}(P_{j_m,t})$$

$$\gamma_{j_0} + \gamma_{j_1} + \cdots + \gamma_{j_m} = 1$$

Where

$$0 = P_{j_0,t} \leq P_{j_1,t} \leq \cdots \leq P_{j_m,t}$$

$$0 = C_{j,t}^{P}(P_{j_0,t}) \leq C_{j,t}^{P}(P_{j_1,t}) \leq \cdots \leq C_{j,t}^{P}(P_{j_m,t})$$

$p_{j,t}$: generation output, continuous variable

$C_{j,t}^{P}(p_{j,t})$: incremental energy offer cost at $p_{j,t}$

$\gamma_{j_0}, \gamma_{j_1}, \ldots, \gamma_{j_m}$: nonnegative **continuous** variables

** Previous PWL formulation is very different but with similar performance*

– Revised PWL results in tighter MIP model

$$\gamma_{j_1} + \cdots + \gamma_{j_m} \le u_{j,t}$$

$$p_{j,t} = \gamma_{j_1} \cdot P_{j_1,t} + \cdots + \gamma_{j_m} \cdot P_{j_m,t}$$

$$C^P_{j,t}(p_{j,t}) = \gamma_{j_1} \cdot C^P_{j,t}(P_{j_1,t}) + \cdots + \gamma_m \cdot C^P_{j,t}(P_{j_m,t})$$

where $u_{j,t}$ is the binary commitment variable

With $0 \le u_{j,t} \le 1$, the revised PWL model always results in higher relaxed MIP solution and tighter model.

- Group variables with same impact on transmission constraints to significantly reduce non-zeros (AGG)

Observed that MIP may converge slowly when there are multiple resources at the same station (may be at different buses)

Aggregate buses into one group if their impact on all transmission constraints are the same

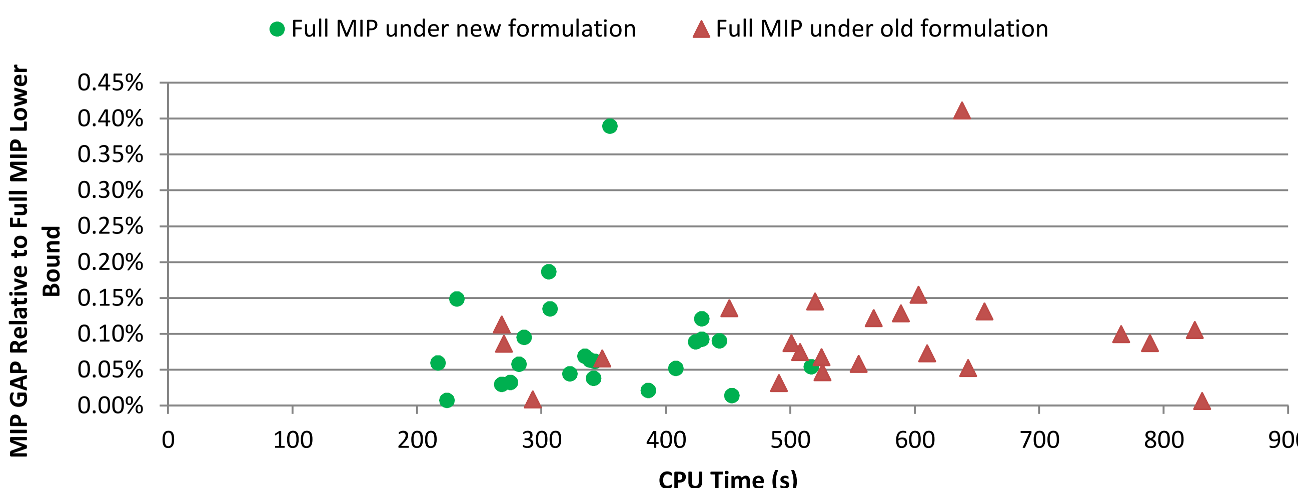
- Introduce a new continuous variable as the sum of all energy dispatch variables under one group
- This new continuous variable is used to represent the group on the LHS of all transmission constraints
  - Significantly reduce non-zeros
  - MIP can converge much better for some cases

- New formulation can significantly improves SCUC performance
  - Hard cases can converge much better with 1200s time limit

Hard cases (1200s time limit)	MIP Gap			
	Original	**With both PWL and AGG**	With only PWL	With only AGG
H-1	1.63%	**0.25%**	0.47%	1.32%
H-2	0.97%	**0.49%**	0.83%	0.43%
H-3	99.99%	**1.36%**	10.81%	38.14%
H-4	54.70%	**2.56%**	12.45%	6.52%
H-5	54.76%	**3.20%**	4.21%	8.61%
H-6	110.72%	**3.32%**	14.46%	154.15%
H-7	27.58%	**8.62%**	8.41%	6.00%
H-8	0.60%	**0.74%**	0.60%	0.70%
H-9	10.07%	**0.70%**	0.25%	0.16%
Average	40.11%	**2.36%**	5.83%	24.00%

Need to increase MIP solving time in production to reach good commitment solution for those days

  - Normal cases can solve much faster to the MIP gap tolerance



Results (23 normal DA cases)

- The new formulation can significantly improve MIP performance for configuration based combined cycle modeling
  - Under each CC group, multiple configurations are at the same locations
  - Prototype SCUC test results on cases with 21 configuration based CC group modeling data collected from participants

	Configuration based CC Modeling			
	Original		New	
Case	CPU Time (s)	MIP Gap	CPU Time (s)	MIP Gap
C-1	639	0.01%	318	0.07%
C-2	1617	0.07%	782	0.08%
C-3	1694	0.06%	806	0.10%
C-4	1091	0.18%	724	0.63%
C-5	2790	1.60%	1200	0.55%

  - Need to expand to ~50 CC groups in production system and more for projected future growth
  - Need more testing on performance consistency

Next step: R&D collaboration on developing future market clearing engine

Proof-of-concept with Gurobi on improving solver performance with distributed and parallel computing

- Hardware: a cluster of ~16 computers connected by network
- Using distributed computing to solve high quality feasible solutions in parallel with different MIP search strategies on different nodes
  - Searching with constraint hint and variable hint
  - Applying different heuristics, …
- Incorporate "polishing step" inside the solver by specifying logic grouping of sets of variables
  - E.g. all binary variables associated with one out-of-money unit are grouped together
  - Automate MISO polishing step to avoid locally non-optimal solution (i.e., issue of small units not committed due to nonzero MIP gap tolerance)
  - Using parallel computing to improve the performance of polishing

Proof-of-concept with GE to explore next generation market clearing engine

- Increase parallelization
- Reduce overhead from e.g., programming language
- Direct interaction with solvers and network analysis packages
- Allow expanding to distributed solution approach

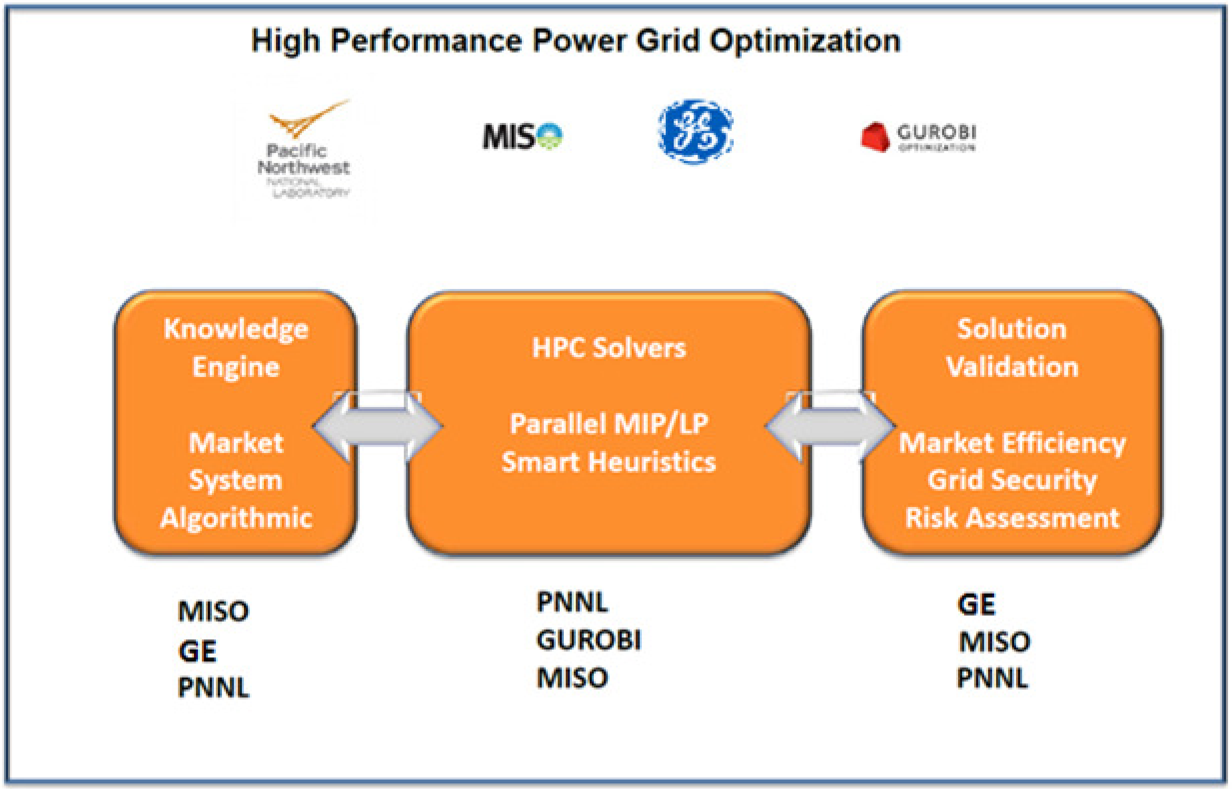
Proof-of-concept on other solution approaches that can potentially be used in parallel to speed up the search for high quality solutions

- PROBE with PowerGem
- Surrogated Lagrangian Relaxation with Uni. Of Connecticut
- ADMM with Stanford
- Other …

ARPA-E High-performance Power-Grid Optimization (HIPPO) project

- Three-year project to explore high performance computing

Integrated team including RTO, vendor, optimization solver, R&D institution



PNNL
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- Steve Elbert
- Henry Huang
- Yuri Makarov
- Matthew Oster
- Postdocs/staffs

GUROBI
- Ed Rothberg

GE
- David Sun
- Xing Wang
- Jie Wan
- But-Chung Chiu

MISO
- Yonghong Chen
- Fengyu Wang
- IT staff

Broader future market platform discussion at MISO

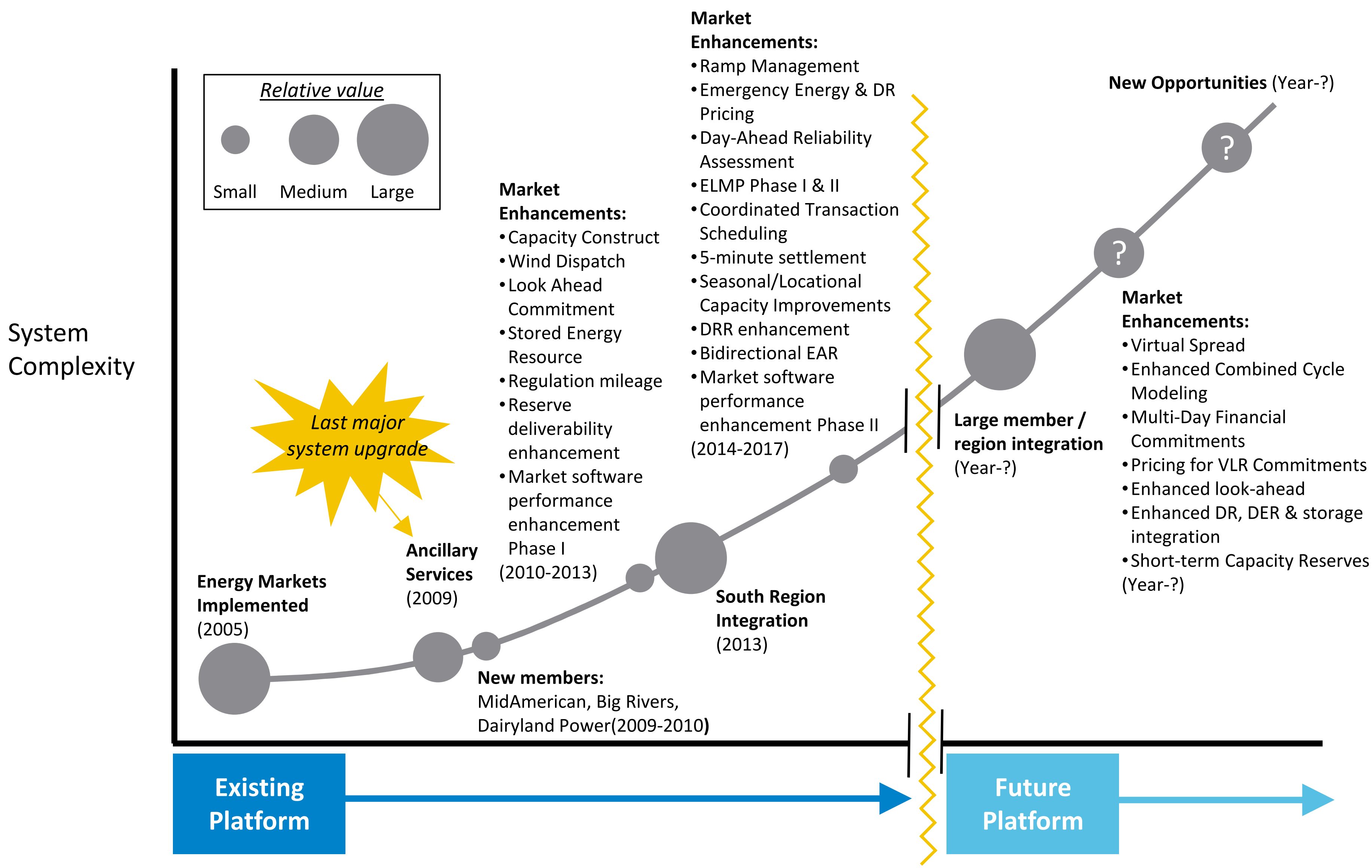
- Workshop to analyze potential impact of industry trend and emerging technology on platform requirement
  - EPA – Clean Power Plan and other rules
  - Gas electricity coordination
  - Seams coordination
  - Infrastructure development
  - Emerging grid monitoring and control technology
  - Distributed energy resources
  - Storage
  - ……

Next generation platform is an enabler for value creation

- Existing market roadmap projects
  - Enhanced combined cycle modeling
  - Multi-day financial commitment
  - Next phase(s) of ELMP
  - Virtual spread product
- Industry trend and emerging technology (less certain but with potentially larger impact)
  - Storage optimization
  - Gas co-optimization
  - Large participation of demand response and distributed energy resources
  - Granular DA study intervals to better manage intra-hour flexibility challenges
  - Shorter clearing window
  - Footprint expansion

Requirements on market clearing software

- Increased number of continuous variables and integer variables
- Larger and more complicated constraints
- Less solving time


Relative value
Small
Medium
Large
System Complexity
Last major system upgrade
Energy Markets Implemented (2005)
Ancillary Services (2009)
New members: MidAmerican, Big Rivers, Dairyland Power(2009-2010)
Market Enhancements:
• Capacity Construct
• Wind Dispatch
• Look Ahead Commitment
• Stored Energy Resource
• Regulation mileage
• Reserve deliverability enhancement
• Market software performance enhancement Phase I
(2010-2013)
South Region Integration (2013)
Market Enhancements:
• Ramp Management
• Emergency Energy & DR Pricing
• Day-Ahead Reliability Assessment
• ELMP Phase I & II
• Coordinated Transaction Scheduling
• 5-minute settlement
• Seasonal/Locational Capacity Improvements
• DRR enhancement
• Bidirectional EAR
• Market software performance enhancement Phase II
(2014-2017)
Large member / region integration (Year-?)
Market Enhancements:
• Virtual Spread
• Enhanced Combined Cycle Modeling
• Multi-Day Financial Commitments
• Pricing for VLR Commitments
• Enhanced look-ahead
• Enhanced DR, DER & storage integration
• Short-term Capacity Reserves
(Year-?)
New Opportunities (Year-?)
?
?
Existing Platform
Future Platform